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The Selective Erosion of Plant Nutrients in Runoff[1]

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ABSTRACT

The enrichment of several P forms (Bray I, labile, inorganic, and organic), N, C, and K in runoff sediment was investigated for six soils of varying physical and chemical composition, using simulated rainfall (60 and 120 mm h^{-1}). Differing enrichment ratios (ER) for C, N, and organic P (2.00, 1.61, and 1.47 avg for the six soils) indicate that erosion may reduce the C/N/organic P ratio of the remaining surface soil. Average ERs, for Bray I (2.45) and labile P (2.89) were significantly greater than for the other P forms (1.48). This was attributed to less aggregation of sediment compared to source soil for the major proportion (70%) of the runoff events studied. Phosphorus desorption-sorption characteristics, buffer capacity (1.49), sorption index (1.56), equilibrium P concentration (1.80), and exchangeable K (2.46) were also enriched in runoff sediment compared to source soil. The logarithm of ER for each P form, N, C, and K was related to the logarithm of soil loss, which ranged from 10 to 800 kg ha^{-1}. Statistically significant differences between regression equations for each nutrient indicate that more than one equation is needed to estimate different nutrient ERs. Nutrient ER was related to clay and specific surface area ER of the sediment. This is to be expected as the nutrients described are chemically associated with clay-sized particles. The potential use of ERs in estimating the effect of erosion on soil fertility is discussed.

Additional Index Words: **available P, Bray I P, enrichment ratio, exchangeable K, labile P, N, organic C, P, soil fertility, soil productivity, water quality.**

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THE SELECTIVE REMOVAL of plant nutrients with runoff sediment is important from both a water quality and soil fertility aspect. At the present time, most water quality models consider only the total amount of P and N transported with sediment (Knisel, 1980; Sharpley et al., 1982). None of the models attempt to estimate the bioavailable fraction. Although sediment-bound nutrients may account for up to 90% of the total amount transported in runoff (Schuman et al., 1973a, b), it is recognized that only a portion of this is available for biological uptake in water bodies (Sonzogni et al., 1982). Twenty percent of the sediment total P (TP) has been assumed to be biologically available (Lee et al., 1979). Since better estimates of the response of a water body to soil nutrient input are needed for eutrophication-agricultural management decisions, a means of estimating the transport in runoff of soil nutrients available for algal uptake is required.

The impact of erosion on soil fertility and productivity has recently received national attention (Williams, 1981). The selective removal of plant nutrients P, N, and K in runoff will reduce soil fertility and

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Table 1. Physical and chemical properties of the soils used.

Soil	Particle size analysis: 2 mm–50 μm	50–20 μm	20–5 μm	5–2 μm	2 μm	Specific surface area	pH	Organic C	Total N	Exchangeable K
	%					$m^2 g^{-1}$		$g kg^{-1}$	$mg kg^{-1}$	
Bernow	74 (79)†	10 (14)	6 (3)	2 (1)	8 (3)	236 (136)	6.3	7.1	620	4.9
Durant	34 (53)	11 (34)	24 (9)	12 (2)	19 (1)	570 (223)	7.1	5.2	490	15.7
Houston Black	10 (80)	6 (7)	19 (6)	15 (1)	50 (5)	1161 (180)	7.9	22.1	1430	26.7
Kirkland	33 (64)	34 (27)	16 (5)	4 (1)	13 (0.5)	478 (195)	6.0	20.2	1310	8.3
Muskogee	21 (66)	20 (24)	18 (5)	12 (1)	29 (4)	781 (203)	6.0	8.6	760	3.1
Teller	28 (50)	19 (33)	23 (12)	8 (1)	22 (4)	641 (264)	6.3	8.5	740	7.6

† Figures in parenthesis are for undispersed soil.

subsequently productivity, unless they are replaced through the application of costly fertilizers. It may be possible to quantify the effect of erosion on soil fertility and productivity using runoff enrichment studies.

Enrichment ratios (ER), calculated as the ratio of the nutrient content of sediment (eroded soil) to that of source soil, have been determined for TP, total N (TN), particulate organic C (OC), and exchangeable K (K) (Knoblauch et al., 1942; Neal, 1944; White and Williamson, 1977). Less information is available on the ER of plant available nutrient forms, although values of 3.4 (water-soluble plus pH 3.0 extractable P), 3.35, and 1.79 (0.001 M H_2SO_4 P), 1.82, and 2.03 (Bray I P) have been reported for silt loams by Massey and Jackson (1952), Rogers (1941), and Stoltenberg and White (1953), respectively. More recently, negative linear relationships between the logarithms of soil loss and ER for TP and TN have been developed for use in water quality models (Menzel, 1980; Sharpley, 1980). These relationships, however, have not been applied to other nutrient forms.

This paper reports ERs of P forms, TN, OC, and K for several soils subjected to simulated rainfall and the relationships between these ratios and soil loss.

MATERIALS AND METHODS

The effect of soil loss on the enrichment of P (Bray I, labile, bioavailable, total, inorganic, organic, and sorbed P), TN, and OC in surface runoff from several soils was investigated using simulated rainfall. The soils studied were Bernow (fine-loamy, siliceous, thermic Glossic Paleudalfs), Durant (fine, montmorillonitic, thermic Vertic Argiustolls), Houston Black (fine, montmorillonitic, thermic Udic Pellusterts), Kirkland (fine, mixed, thermic Udertic Paleustolls), Muskogee (fine, loamy, mixed, thermic Typic Argiudolls), and Teller (fine-loamy, mixed, thermic Udic Argiustolls) and represent major soil types in Oklahoma and north Texas.

Surface samples (0–100 mm depth) of each soil were collected, air-dried, sieved (2 mm), packed in duplicate 1-m long, 0.3-m wide, and 0.15-m deep boxes to field bulk density (approx. 1.35 Mg m^3) and slowly wetted (Sharpley, 1980). Phosphorus ($CaH_2PO_4 \cdot H_2O$) at rates of 0 and 57 mg P kg $soil^{-1}$ (equivalent to 0 and 30 kg P ha^{-1} surface applications) and N (as KNO_3) at rates of 0 and 190 mg N kg $soil^{-1}$ (equivalent to 0 and 90 kg N ha^{-1} surface applications) was mixed with 3-kg increments of soil during packing to a 40-mm depth. Rainfall intensity, soil slope, and soil cover were varied to induce a range in suspended sediment concentration of runoff. Rainfall was applied at 60 and 120 mm h^{-1} intensities with a drip-tube type simulator (Munn and Huntington, 1976) for 1 h (2- and 100-yr rainfalls, respectively, in Oklahoma and north Texas). Soil boxes were inclined to create 4 and 8% slopes and screens (2- and 1-mm^2 mesh) were placed 40-mm above the soil surface to reduce the kinetic energy of raindrop impact. Surface soil samples (0–10 mm) were taken from each box prior to rainfall application, air-dried, sieved (2 mm), and stored at 0 to 4°C until analysis. Suspended sediment transported from each box during runoff was separated from runoff water by settling and decantation, air-dried, and stored at 0 to 4°C until analysis. Suspended sediment concentration of runoff was determined in duplicate as the difference in weights of 250-mL aliquots of unfiltered and filtered samples after evaporation to dryness.

Particle size distribution of soil and suspended sediment transported in each runoff event was determined by pipette analysis, with and without dispersion by sodium hexametaphosphate (Day, 1965). Specific surface area was calculated as 0.05 (% sand) + 4.0 (% silt) + 20 (% clay), where sand, silt, and clay are the proportion of material between 2 mm − 50 μm, 50 − 2 μm, and <2 μm, respectively (Foster et al., 1980). Soil pH was determined using a glass electrode at a 5:1 water/soil ratio (weight/weight), particulate OC by dichromatic-wet combustion (Raveh and Avnimelich, 1972), and TN by a semimicro Kjeldahl procedure (Bremner, 1982). Exchangeable K was extracted from 2 g of soil with 20 mL neutral 1 M NH_4OAc for 15 min and determined by atomic absorption on filtered extracts (Knudsen et al., 1982).

The following P forms and P desorption-sorption characteristics were also measured on both surface soil prior to rainfall and suspended sediment from each runoff event. Bray I P (BP) was determined by the method of Bray and Kurtz (1945) and labile P (LP) by isotopic dilution of P^{32} (Olsen and Sommers, 1982). Bioavailable P (BIOP) was that extracted by 0.1 M NaOH in 17 h at a solution to soil ratio of 1000:1 (Williams et al., 1980). Total P was determined by perchloric acid digestion and inorganic P (IP) by acid (0.5 M H_2SO_4) extraction (Walker and Adams, 1958). Organic P (OP) was expressed as the difference between TP and IP.

Phosphorus buffer capacity (PBC) and equilibrium P concentration (EPC) were determined by shaking 1-g samples of soil with 40 mL of distilled water containing various amounts of P (0–0.5 μg P L^{-1} added as K_2HPO_4) and 2 drops of toluene on an end-over-end shaker for 40 h. The samples were then centrifuged (266 km s^{-1}), filtered (0.45 μm), and the concentration of solution P determined. The amount of P sorbed was calculated by difference and a P sorption isotherm, restricted to low solution P concentration, subsequently constructed. The EPC supported by the soil (White and Beckett, 1964) was obtained from the isotherm as the solution P concentration (mg L^{-1}) at which no net desorption or adsorption (mg kg^{-1}) occurred. The slope of the isotherm at this point was taken as equivalent to the equilibrium PBC at EPC (Holford, 1979). The amount of P sorbed, X (mg P kg^{-1}), from one addition of 1.5 g P kg $soil^{-1}$ (added

Table 2. Phosphorus content and desorption-adsorption properties of the soils used.

Soil	P content						Buffer capacity	Sorption index	EPC
	Bray	Labile	Bio†	Total	Inorg	Org			
	mg P kg^{-1}						L kg^{-1}		g L^{-1}
Bernow	19	18	27	144	67	77	45	68	89
Durant	6	16	39	234	94	140	80	94	64
Houston Black	10	39	10	481	272	209	120	210	130
Kirkland	8	19	30	303	137	166	7	74	57
Muskogee	2	24	35	154	33	121	61	58	14
Teller	5	28	39	132	33	99	76	89	47

† Bio represents 0.1 *M* NaOH extractable "bioavailable" P.

Table 3. Mean and standard deviation (in parenthesis) enrichment ratios for specific surface area, clay, P forms, organic C, total N, and K over a range in soil loss (10–800 kg ha^{-1}) (n = 21).†

	Bernow	Durant	Houston Black	Kirkland	Muskogee	Teller
Surface area‡	1.33(0.37)a	1.38(0.35)a	1.49(0.35)a	1.26(0.30)a	1.23(0.25)a	1.19(0.21)a
Clay	1.61(0.53)b	1.86(0.73)b	1.58(0.46)a	1.50(0.41)b	1.37(0.43)abc	1.41(0.44)bc
Bray 1P	2.66(0.70)c	1.87(0.33)b	2.41(0.67)b	2.39(0.66)c	2.72(0.42)d	2.67(0.46)d
Labile P	2.93(0.70)c	3.04(1.26)c	3.04(1.10)c	2.84(1.03)d	2.77(1.17)d	2.69(0.74)d
Bioavailable P	1.58(0.23)b	1.50(0.24)ae	1.62(0.24)a	1.43(0.21)ab	1.36(0.20)abc	1.42(0.18)bc
Total P	1.44(0.26)ab	1.69(0.37)be	1.50(0.30)a	1.40(0.29)ab	1.30(0.16)ab	1.41(0.20)bc
Inorganic P	1.60(0.36)b	1.61(0.30)e	1.42(0.24)a	1.37(0.24)ab	1.53(0.22)c	1.63(0.30)ef
Organic P	1.43(0.31)ab	1.81(0.37)b	1.53(0.33)a	1.46(0.23)ab	1.28(0.35)ab	1.31(0.19)ab
P buffer capacity	1.51(0.28)ab	1.68(0.39)be	1.56(0.37)a	1.41(0.33)ab	1.27(0.20)a	1.48(0.20)cf
P sorption index	1.62(0.27)bd	1.82(0.48)b	1.47(0.27)a	1.49(0.21)b	1.45(0.26)bc	1.48(0.22)cf
EPC	−1.83(0.66)e	−2.10(0.57)d	−1.88(0.64)e	−1.84(0.41)e	−1.78(0.38)e	−1.35(0.60)bc
Organic C	2.01(0.92)e	2.46(0.68)g	2.44(1.23)b	1.97(0.57)e	1.48(0.23)bc	1.65(0.46)e
Total N	1.73(0.50)d	2.23(0.41)d	1.64(0.40)a	1.53(0.36)a	1.28(0.37)a	1.23(0.32)a
Exchangeable K	2.47(1.37)f	2.45(1.62)g	2.56(1.06)b	2.41(0.99)c	2.39(0.73)f	2.45(1.57)d

† Means for a given soil followed by the same letter are not significantly different (5% level) as measured by analysis of variance for paired data. Statistical analysis between soils could not be carried out.
‡ Dispersed specific surface area and clay enrichment ratio, respectively.

as K_2HPO_4) was determined after end-over-end shaking for 40 h at a water to soil ratio of 100:1. The P sorption index (PSI) was calculated using the quotient $X \log C^{-1}$, where C is solution P concentration (mg L^{-1}) (Bache and Williams, 1971). This quotient was highly correlated with P sorption maxima calculated from a Langmiur sorption plot for a wide range of soils (Bache and Williams, 1971).

For all samples, the concentration of P was determined colorimetrically on filtered samples by the molybdate-blue method (Murphy and Riley, 1962). Acid or alkali filtrates were neutralized prior to P determination.

In the following discussion, data reported are mean values of duplicate treatments and differences between nutrient forms, indicated statistically significant, refer to the 5.0% level, as determined by analysis of variance for paired data.

RESULTS AND DISCUSSION

The soils used possessed a wide range in texture (8–50% clay content) and specific surface area (236–1161 × 10^3 m^2 kg^{-1}) (Table 1). Similarly, P forms, TN, OC, and K contents of soils prior to fertilizer P and N application exhibited up to a 10-fold variation (Tables 1 and 2). Soil P desorption-sorption characteristics (PBC, PSI, and EPC) also varied among the soils (Table 2).

Comparison of Enrichment Ratios

Enrichment ratios for specific surface area, clay, P, TN, OC, and K were determined as the ratio of runoff sediment content to surface soil content before runoff. Mean ERs were calculated for each soil based on 21 runoff events, for which soil loss ranged from 10 to 800 kg ha^{-1} (Table 3). These values are presented for comparison between nutrient forms and soil type only, as ER varies with soil loss. The enrichment of clay was significantly greater than that of specific surface area for all soils except Houston Black and Muskogee (Table 3). Dispersed clay and specific surface area ER are included, since they are estimated in soil erosion models (Foster et al., 1980) and are involved in nutrient reaction with eroded soil. For most soils, mean ERs for BP (except Durant), LP, OC (except Muskogee), and exchangeable K were significantly greater than clay and dispersed specific surface area ER. In contrast, mean ERs of the remaining P forms and N (except Durant) were not significantly different than dispersed clay or specific surface area enrichment (Table 3). Although the transport of P, N, and C is primarily associated with clay-sized mineral and organic particles, enrichment of BP, LP, OC, and K in runoff sediment exceeded that associated with the selective erosion of fines.

The enrichment of OC, TN, and OP in runoff were dissimilar (Table 3). Mean ERs for OC were significantly greater than both TN and OP for all soils, and although TN and OP enrichments were not significantly different for most soils, TN values were slightly higher than OP. Knoblauch et al. (1942) and Neal (1942) also observed higher organic matter (4.31) and TN (4.12) than TP (1.84) (OP was not measured) ERs in runoff from Collington sandy loam in New Jersey. As a result, the selective erosion of organic nutrients may lead to a decrease in the C/N/OP ratio of the remaining surface soil. It is, thus, apparent, that under the present experimental conditions, organic matter transported in runoff may differ from that of surface soil due to the preferential transport of certain organic complexes of differing C/N/P ratio.

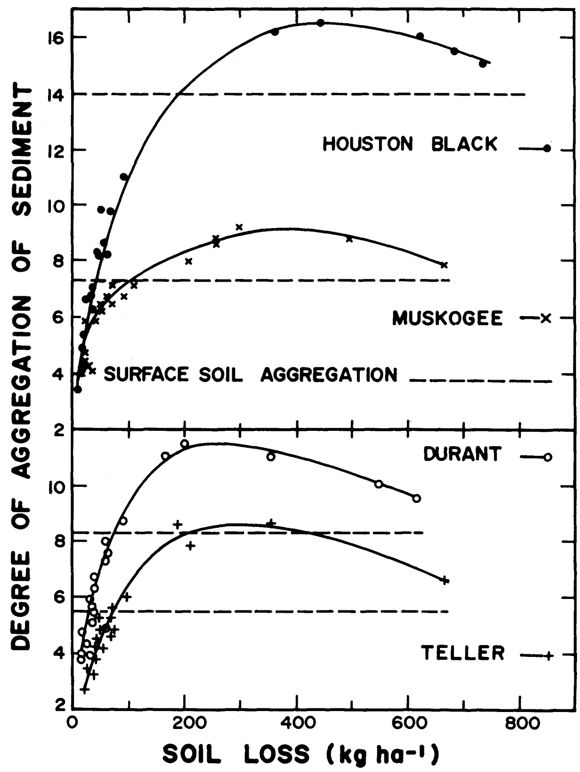

Fig. 1. The degree of aggregation of runoff sediment (ratio of clay content of dispersed and undispersed sediment) as a function of soil loss at several rainfall intensities (60 and 120 mm h^{-1}) soil slopes (4 and 8%) and cover. Dashed line represents surface soil aggregation.

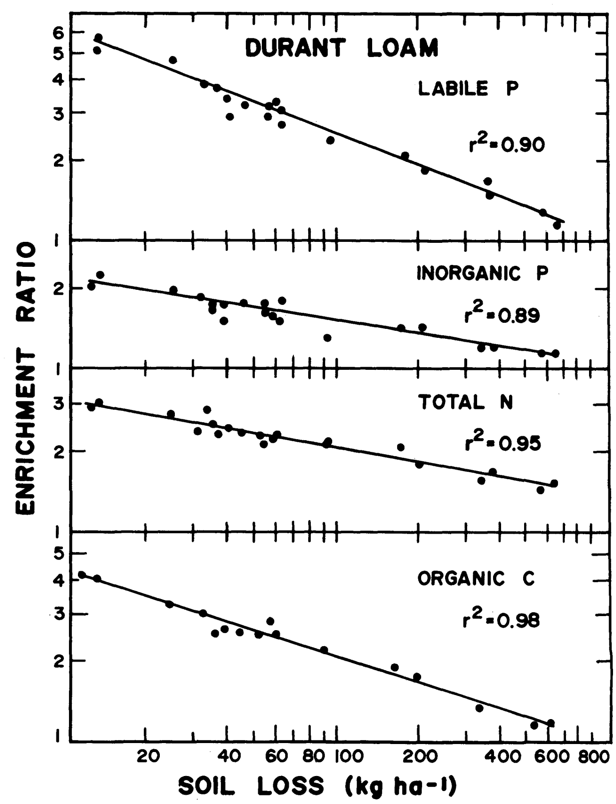

Fig. 2. Relationship between logarithm of soil loss and logarithm of enrichment ratio (sediment/soil content) for labile P, inorganic P, total N, and organic C for Durant loam.

Mean ER for LP and BP (except Durant) were significantly greater than the other P forms measured (Table 3). Although P transport in runoff is associated with clay-sized particles, the preferential transport of BP and LP cannot be solely accounted for by clay enrichment (Table 3). Apparently, the extractability of BP or LP increased during erosion compared to the source soil. This increase may result from a selective erosion of certain clay minerals and fine clays having an increased BP and LP content and/or a decrease in particle aggregation compared to the surface soil. Although Murad and Fischer (1978) and Rhoton et al. (1979) observed preferential clay mineral erosion in West Germany and Ohio watersheds, respectively, this is not expected to be important in simulated runoff from the packed 0.3-m^3 boxes of the present study and no particle size separation of 2 μm material was made.

The degree of aggregation of surface soil and runoff sediment was represented by the ratio of the proportion of clay in dispersed to undispersed samples. As the degree of aggregation increases, the proportion of clay associated with aggregates increases. As soil loss for individual runoff events increased, the degree of aggregation of runoff sediment increased to some peak and then decreased at a much slower rate (Fig. 1). Similar results were obtained for Bernow and Kirkland soils (data not presented). For events of low soil loss, runoff energy was insufficient to transport large aggregates and the degree of sediment aggregation was less than that for surface soil (represented by the dashed line on Fig. 1). As soil loss and runoff energy increased, larger aggregates were transported, until a loss is reached where turbulent mixing in runoff was sufficient to cause aggregate breakdown (Fig. 1). As the degree of aggregation increases it is expected that a greater proportion of P may be physically protected and be less extractable (as measured by BP and LP). Since the degree of sediment aggregation was less than that of surface soil for most runoff events (73% of the events averaged for all soils), it is suggested that a greater proportion of runoff sediment P will be available, as reflected by higher mean BP and LP ERs than for the other P forms (Table 3). The fact that the mean BIOP ER was lower than that of BP and LP ERs (Table 3), may result from a breakdown of organically-bound aggregates by the BIOP alkali extractant (0.1 *M* NaOH).

Soil P desorption-sorption reactions are generally associated with clay-sized particles; therefore, mean PBC and PSI ERs were statistically the same as clay enrichment. In the case of EPC, runoff sediment maintained a lower value than surface soil, hence the negative ER (Table 3). Buffer capacity is inversely related to the ease with which LP will move into solution (Holford, 1979). Consequently, PBC and EPC will be useful in water quality modeling in terms of expressing the extent to which suspended sediment can modify the soluble P concentration of runoff when used in conjunction with the EPC and LP content of suspended sediment.

Although a statistical comparison of ER between soils cannot be made since soil loss varied from soil

Table 4. Regression analysis of the logarithmic relationship between soil loss and enrichment ratio (n = 21).†

	Bernow		Durant		Houston Black		Kirkland		Muskogee		Teller	
P form	Slope‡	Inter‡	Slope	Inter.	Slope	Inter.	Slope	Inter.	Slope	Inter.	Slope	Inter.
Disp. area§	−0.181	1.024a	−0.185	1.080a	−0.170	1.115a	−0.177	1.136a	−0.189	1.056a	−0.178	0.955a
Clay§	−0.291	1.737b	−0.299	1.822b	−0.200	1.291a	−0.297	1.655b	−0.294	1.624b	−0.295	1.627bc
Bray 1 P	−0.161	1.532a	−0.150	1.247a	−0.209	1.753a	−0.158	1.784a	−0.166	1.749a	−0.169	1.726a
Labile P	−0.343	2.601b	−0.386	2.665c	−0.281	2.272b	−0.353	2.533b	−0.349	2.580b	−0.345	2.494b
Bioavailable P	−0.151	1.077a	−0.140	0.990a	−0.092	0.873c	−0.159	1.032a	−0.164	1.050a	−0.155	1.040a
Total P	−0.173	0.927a	−0.193	1.318ab	−0.137	0.982c	−0.178	0.983a	−0.189	0.792ac	−0.134#	0.936a
Inorganic P	−0.147#	1.032a	−0.154	1.113a	−0.117	0.850c	−0.144#	1.137a	−0.141	1.066a	−0.222	1.465d
Organic P	−0.143	1.001a	−0.182	1.345ab	−0.145	1.035c	−0.139	0.933a	−0.097	0.683d	−0.145	0.913a
P buffer capacity	−0.160	1.130a	−0.201	1.344ab	−0.166	1.145ac	−0.161	1.226a	−0.164	0.983a	−0.159	1.094a
P sorption index	−0.203	1.479ab	−0.233	1.552b	−0.122	0.904c	−0.199	1.133a	−0.197	1.260ac	−0.173	1.155a
EPC	−0.242	1.632b	−0.245	1.740b	−0.250	1.666b	−0.239	1.049c	−0.228	1.600c	−0.169	1.046a
Organic C	−0.292	1.821b	−0.317	2.191d	−0.333	2.255d	−0.284	1.733bc	−0.172	1.168a	−0.271	1.682cd
Total N	−0.169	1.003a	−0.178	1.539a	−0.173	1.225ac	−0.155	0.924a	−0.143	0.894a	−0.101	0.651a
Exchangeable K	−0.351	2.411b	−0.367	2.452c	−0.343	2.338d	−0.342	2.437b	−0.366	2.487b	−0.373	2.460b

† For a given soil regression followed by the same letter are not significantly different at the 5.0% level as determined by analysis of variance for paired data.
‡ Slope and intercept of the regression equation.
§ Dispersed specific surface area and clay, respectively.
# Relationships statitically significant at the 1.0% level, remaining relationships are significant at the 0.1% level.

to soil, mean values were similar for a given nutrient form (Table 3).

Erosion and Water Quality

A highly significant linear relationship between the logarithms of soil loss and ER of each nutrient form was observed (Fig. 2). The slopes and intercepts for each regression are presented in Table 4. This logarithmic relationship, presently used in water quality models to predict TP and TN transport in runoff (Knisel, 1980), can therefore, be used to predict the transport of sediment-associated BP, LP, BIOP, OP, OC, and K in runoff. In addition, P desorption-sorption characteristics of runoff sediment can also be estimated. It is apparent, however, that regression equations for LP, EPC, OC, and K had higher slope and intercept values and were significantly different from the remaining nutrients. Although statistical comparison of relationships between soils was not possible, regression equations were similar for soils ranging in texture from a fine sandy loam (Bernow) to a clay (Houston Black) under similar experimental conditions. Consequently, more than one regression equation is needed to estimate the ER of several plant nutrients. Based on statistical differences between the regression equations for each nutrient, slope and intercept values were calculated for statistically similar nutrient forms using all runoff events averaged for all soils. The following equations were thus developed for BIOP, BP, TP, IP, OP, PBC, PSI, and TN:

$$\ln \text{ER} = 1.21 - 0.16 \ln \text{soil loss (kg ha}^{-1}) \quad [1]$$

for LP, and K;

$$\ln \text{ER} = 2.48 - 0.35 \ln \text{soil loss} \quad [2]$$

and for EPC and OC:

$$\ln \text{ER} = 1.63 - 0.25 \ln \text{soil loss}\,. \quad [3]$$

Slope and intercept values of the regression equation for TP and TN (Eq. [1]) are lower than values used previously (−0.27 and 2.48 for TP and −0.20 and 2.00 for TN) (Menzel, 1980; Sharpley et al., 1982). These differences may result in part from the fact that the earlier equations were developed from runoff events of higher soil loss (40–2300 kg ha^{-1}). Enrichment ratios (Fig. 3) and nutrient contents of runoff sediment predicted by Eq. [1], [2], and [3] were not significantly different from measured values for individual simulated rainfall events. The grouping of nutrient forms as above, provides a simplified approach. If a more accurate prediction of nutrient transport is required, individual regression equations in Table 4 can be used.

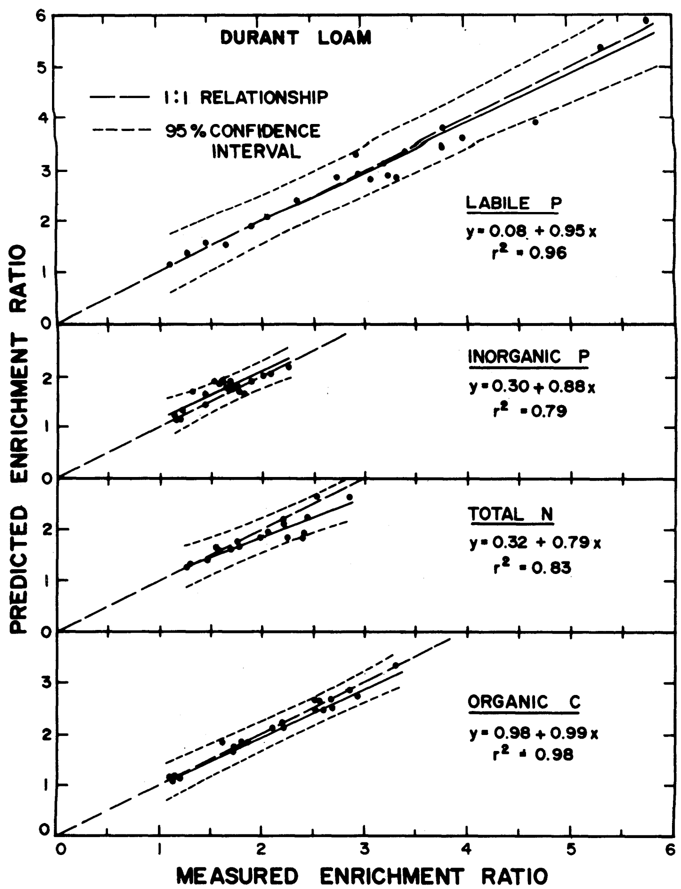

Fig. 3. Relationship between measured enrichment ratios (sediment/surface soil content) for labile P, inorganic P, total N, and organic C and ratio predicted by Eq. [1], [2], and [3] for Durant loam.

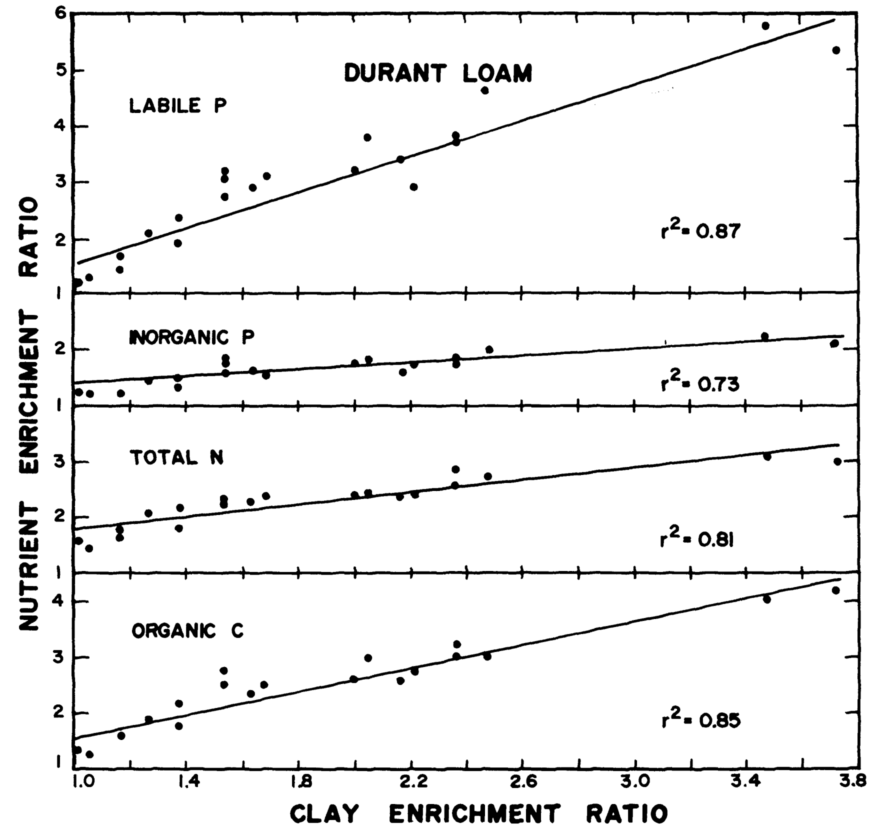

Fig. 4. Relationship between the enrichment ratio (sediment/soil content) of clay and labile P, inorganic P, total N, and organic C for Durant loam.

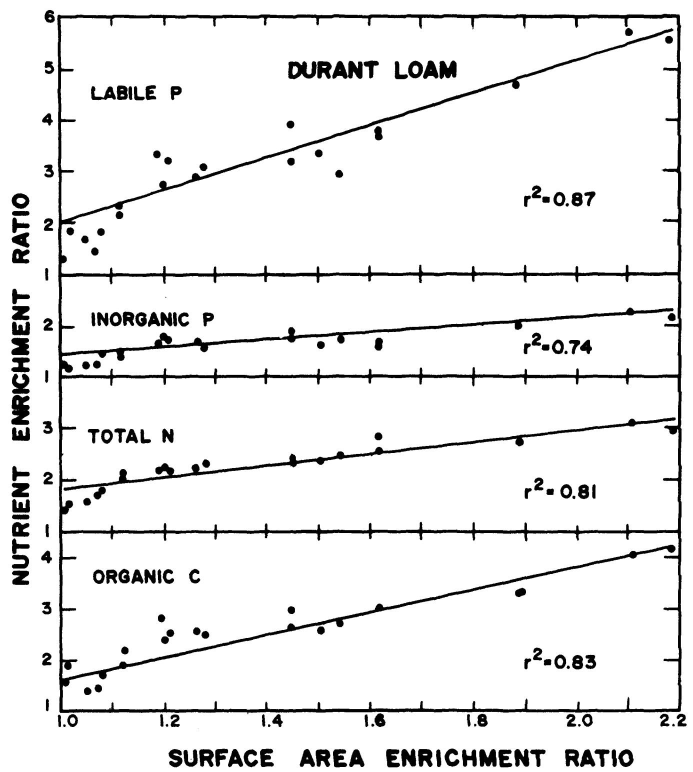

Fig. 5. Relationship between the enrichment ratio (sediment/soil content) of surface area and labile P, inorganic P, total N, and organic C for Durant loam.

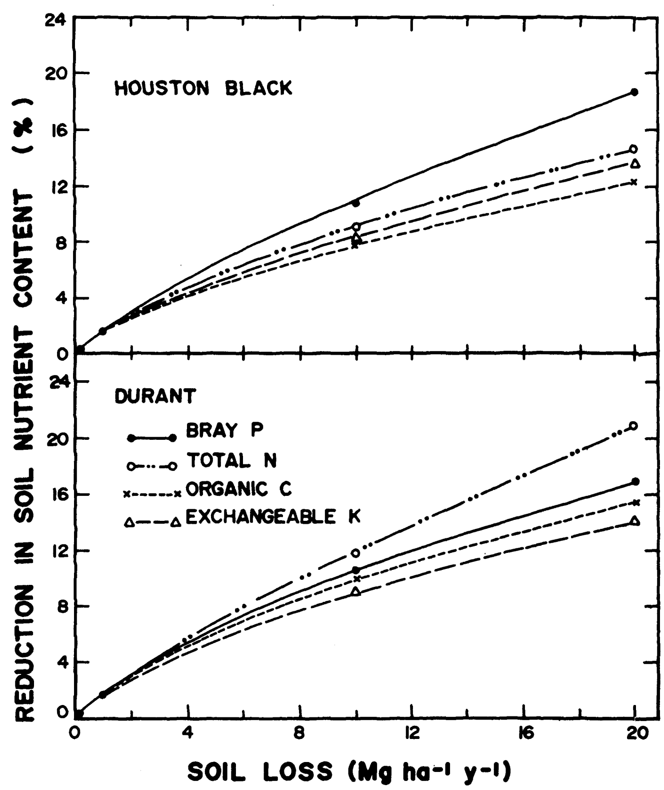

Fig. 6. The reduction in soil nutrient content as a function of soil loss for Houston Black and Durant soils.

Each nutrient ER was linearly related to clay ER (Fig. 4) and specific surface area (Fig. 5). Since these relationships are nonlogarithmic, they may provide a more sensitive means of predicting the transport of sediment-bound nutrients, than using soil loss. In addition, clay and specific surface area ER are estimated by erosion models (Foster et al., 1980) and are used to estimate particulate OC and pesticide transport in runoff (Leonard and Wauchope, 1980). However, departure from linearity or error in estimating nutrient ER becomes large as the clay and specific surface area ER decreases below 1.2 (Fig. 4 and 5). Theoretically nutrient ER should be 1.0 when either clay or specific surface area ER is 1.0. Thus, under conditions of high soil loss, when clay or specific surface area ER approaches 1.2, the relationship must be used with caution or a nonlinear model used.

Enrichment Ratios and Soil Fertility

The loss of BP, TN, OC, and K over a 10-yr period as a proportion of the amount (kg ha^{-1}) in the surface 100 mm of Durant and Houston Black (Tables 1 and 2) was calculated using the regression equations of Table 4 (Fig. 6). This calculation demonstrates the potential use of ERs in evaluating the effect of erosion on soil fertility. Since the regression equations used were developed from 0.3-m^2 boxes, the results are not a quantitative estimate of field scale effects. An annual soil loss of 20 Mg ha^{-1} was chosen as the upper limit, as this is approximately twice the rate considered acceptable by soil conservationists (Dempster and Stierna, 1979) and is the average annual loss from U.S. croplands (Duttweiler and Nicholson, 1983). It was assumed that the annual soil loss occurred over an average of 20 events. At a soil loss of 20 Mg ha^{-1}, 20% of the BP in a 100-mm rooting depth can be removed over a 10-yr period by erosion alone (plant uptake not included) (Fig. 6). Although the erosional loss of P, TN, and K can be replaced by fertilizer application, the OC loss will be more important in terms of a decreased soil structure, aeration, and water holding capacity and will be more difficult to replace.

CONCLUSIONS

In recently developed water quality models, estimation of nutrient transport in runoff is limited to TP and TN losses (Knisel, 1980). Other relationships developed here between enrichment ratio and soil loss (Table 4), provide nutrient enrichment ratios necessary to estimate the transport of those associated with sediment. The nutrient forms include bioavailable P, organic C, and K. In addition, the effect of selective erosion on P desorption-sorption properties of runoff sediment can be accounted for by these relationships. Inclusion of these relationships in water quality models will improve the estimation of biological productivity of surface water in response to inputs of nutrients from agricultural runoff and allow a better description of P-runoff sediment interactions. In addition, since the selective erosion of P forms, N, C, and K was not the same for each nutrient form, enrichment ratio is useful for quantifying the effect of erosion on soil fertility and productivity. As Bray I, bioavailable and labile P, P buffer capacity, P sorption index, and equilibrium P concentration of surface runoff sediment have not been routinely monitored in field studies, comparison of predicted and observed data is precluded. These analyses are now being made.

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Influence of Soybean and Corn Cropping on Soil Aggregate Size and Stability[1]

E. E. ALBERTS AND R. C. WENDT[2]

ABSTRACT

Higher rates of soil loss have been observed for soybean [*Glycine max* (L.) Merr.] cropping than for corn (*Zea mays* L.) cropping. The objective of this study was to determine whether 4 yr of continuous soybean and continuous corn cropping had altered the size and stability of soil aggregates within the tillage zone, which could affect soil seal formation and erodibility. Samples for analyses were obtained in June and October of 1980 from the Monona (fine-silty, mixed, mesic, Typic Hapludolls) and Clarion (fine-loamy, mixed, mesic, Typic Hapludolls) soils in Iowa. The mean-weight diameter of dry-sieved aggregates was significantly ($p < 0.05$) lower for soybeans than corn in October, but the values were similar in June. The mean-weight diameter of wet-sieved aggregates was lower for soybeans than corn in both June and October, but the differences were not statistically significant. The mass of clay released from the bulk soil and two macroaggregate size fractions with laboratory shaking was slightly, but significantly ($p < 0.10$), higher for corn than soybeans.

Additional Index Words: **soil structure, soil erodibility, *Glycine max* (L.) Merr., *Zea mays* L., soil tilth.**

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SOYBEAN [*Glycine max* (L.) Merr.] cropping has been found to increase soil loss relative to corn (*Zea mays* L.) cropping (Laflen and Moldenhauer, 1979; and Alberts et al., 1985). One of the factors that could be important in explaining observed differences in soil loss between these crops is the effect of cropping on aggregate size and stability. It is well known that raindrop impact, particularly on a wetted soil, can cause the surface soil aggregates to break down and form an infiltration limiting surface seal.

Soybean and corn cropping effects on aggregate stability have been studied, but the results are inconclusive and divided between those that have (Stauffer, 1946; Bathke and Blake, 1984) and those that have not (Browning et al., 1943; Strickling, 1950) found a detrimental influence of soybean cropping on aggregate stability. Fahad et al. (1982) found that continuous soybean cropping did not reduce the stability of aggregates in the 0- to 30-mm depth; however, some reduction in aggregate stability was noted within the 30- to 300-mm depth.

Aggregate size and stability are dynamic soil properties which change in response to aggregating and disaggregating forces in the field environment (Gish and Browning, 1948; and Strickling, 1950). Because of the nearly infinite variety of climatic, soil, cropping, and tillage factors present in the field, it is not too surprising that there is some lack of agreement in the literature on the relative effects of soybean and corn cropping on aggregate stability. Of the various researchers cited above, only Strickling (1950) obtained soil samples during the seedbed period when the soil was relatively loose and lacking ground cover. It is for this soil condition that maximum stability of the soil aggregates within the tillage zone is needed.

Our intent was to evaluate soybean and corn cropping effects on aggregate size and stability for periods when maximum soil losses usually occur. We tested the hypothesis that 4 yr of continuous soybean and continuous corn cropping had no differential effect on the size and stability of soil aggregates within the tillage zone.

MATERIALS AND METHODS

Soil samples were collected during 1980 from two fertile agricultural soils in Iowa. One soil was located within the deep loess hills region of western Iowa and northwestern Missouri. The soil series sampled was the Monona (fine-silty, mixed, mesic, Typic Hapludolls); located at the Western Iowa Experimental Farm near Castana on an 11% slope. The soil among the sample sites was texturally uniform with a sand, silt, and clay content of 10, 740, and 250 g kg^{-1}, respectively. The other soil was located within the glacial till region of central Iowa and southern Minnesota. The soil series sampled was the Clarion (fine-loamy, mixed, mesic, Typic Hapludolls); located near Ames on a 5% slope. The variation in sand, silt, and clay contents among the sample sites was within 10 g kg^{-1} of the mean values of 520, 280, and 200 g kg, respectively.

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